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Tools and methods for teaching magnetic resonance concepts and techniques

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Published in:
European Medical Physics News

Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

Tools and methods for teaching magnetic resonance concepts and techniques

Abstract

Teaching of MRI methodology can be challenging for teachers as well as students. To support student learning, two graphical simulators for exploration of basic magnetic resonance principles are here introduced. The first implements a simple compass needle analogy implemented for day one of NMR and MRI education. After a few minutes of use, any user with minimal experience of magnetism will be able to explain the basic magnetic resonance principle. A second piece of software, the Bloch Simulator, aims much further, as it can be used to demonstrate and explore a wide range of phenomena including RF interactions, relaxation, weighting, echoes, imaging principles and more. Both simulators run in almost any browser without installation of software, but are also freely available for download. Example uses are documented in a series of short videos available on YouTube.

Introduction

Teaching and learning MRI can be frustrating as many needed concepts are foreign to typical students. Medical physicists are often involved in teaching of technical as well as non-technical staff, e.g., radiologist and radiographers who need a basic understanding of MRI to perform well, especially when measurements do not give the expected results. Besides facing the challenge of understanding MRI themselves, medical physicists therefore also need to explain vector dynamics and field interactions to people who are not familiar with such concepts. They need to understand precession, excitation and relaxation, as well as more complicated time courses central to MRI, e.g. spin evolution during imaging sequences. Many MRI teachers have desperately been waving their arms to illustrate vector dynamics. Probably equally often, the frustration has been on the student side, as math and hand waving not always convey sufficient understanding.

Based on these experiences, graphical simulators tailored for education were developed. The latest versions run directly from the Internet in almost any browser, and are also freely available for download. The "*JavaCompass*" [1] can be

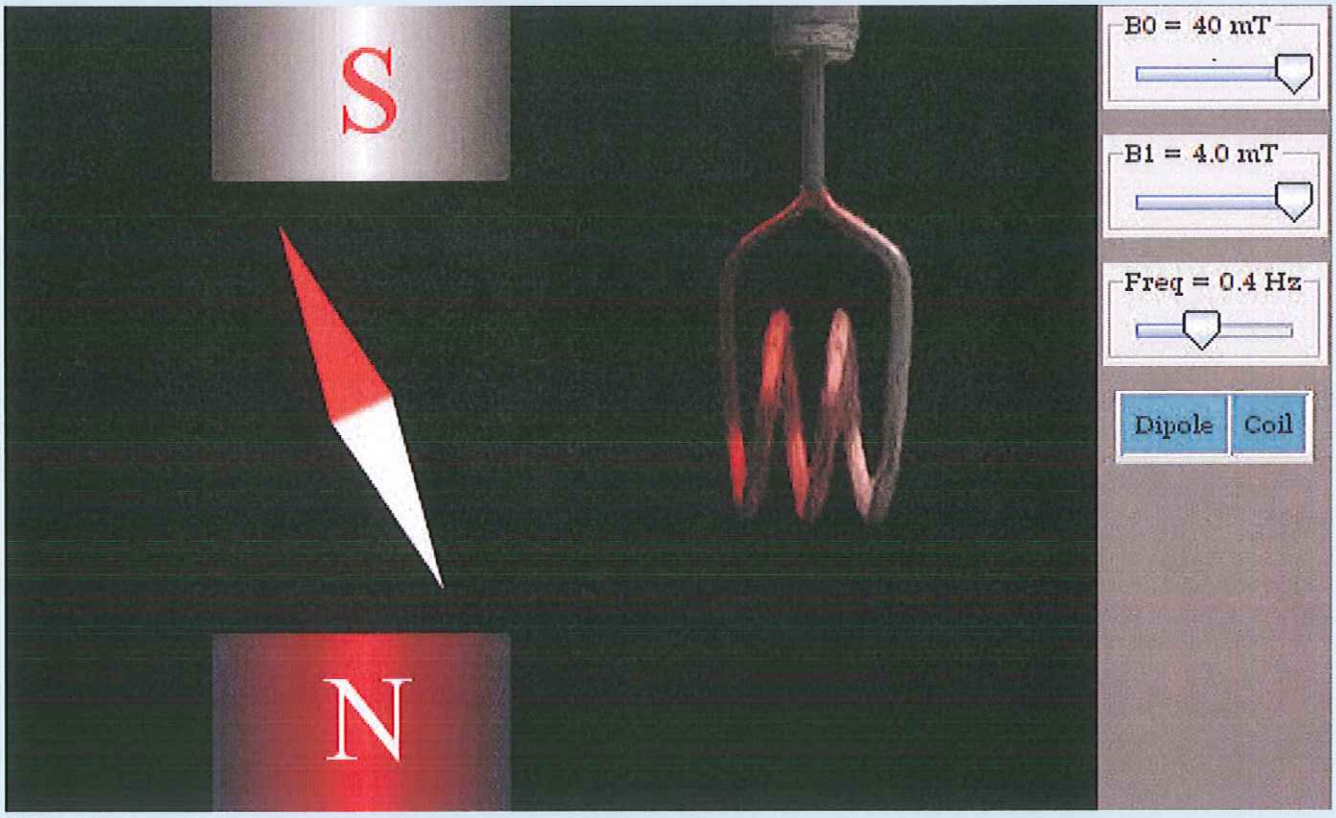

Fig 1: The simplest magnetic resonance phenomenon can be explored using the JavaCompass.

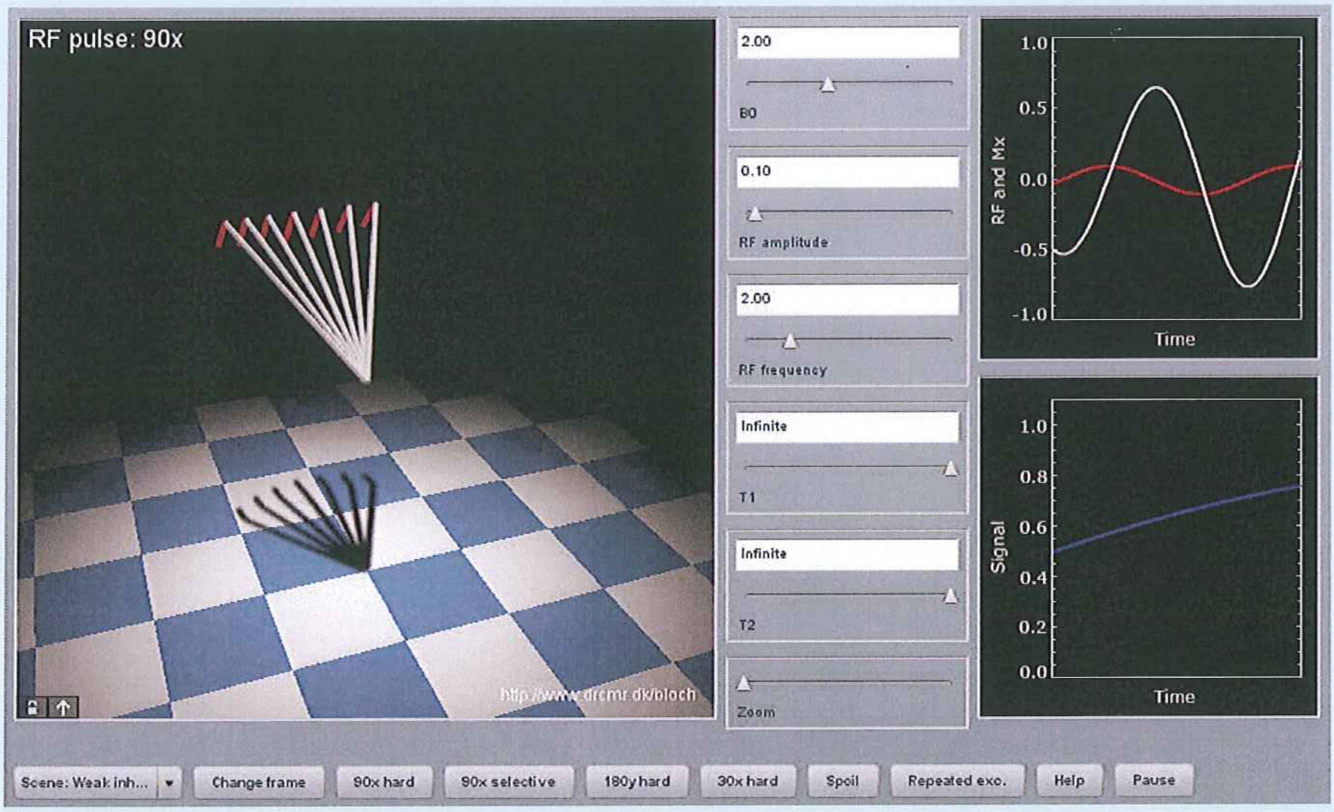

Fig 2: Seven spin isochromates are here manipulated interactively using sliders and event buttons of the Bloch Simulator.

used to demonstrate basic magnetic resonance, transmission, reception, excitation and relaxation. The more advanced "*Bloch Simulator*" [2] implements Bloch dynamics in presence of varying fields as employed during MR sequences, including gradients. This article reviews the software and thoughts behind.

Day One of MR education - the JavaCompass

Even when aimed at non-technical staff, typical introductions to NMR basics take outset in the quantum mechanical eigenstates, spin up and spin down. It is often stated that quantum mechanics (QM) enforces nuclear spins to align parallel or anti-parallel to the polarizing field used in NMR. This claim should be sufficient to confuse most thinking students. In particular they should wonder why nearly half the nuclei align against the field, which is the least energetically favourable and classically least expected orientation. Besides being non-intuitive, that starting point for explaining NMR is actually wrong as quantum mechanics predicts a near-isotropic, slightly skewed distribution of spin orientations, as does classical mechanics [3]. The spin-up and spin-down states are mathematical conveniences (form a basis) that plays no role for the understanding of MR, and employing them in the first introduction may do more harm than good. Instead, the basic MR phenomenon can advantageously be described using *classical mechanics*, and it can be shown using QM that such an explanation is exact in all situations relevant to MRI. Later, quantum mechanics can be introduced for those who need it, e.g., physicist in need of describing advanced spectroscopic methods. Many of those require no QM to be understood, but QM offers a convenient and complete mathematical description.

The *JavaCompass* is a simple piece of software offering an alternative introduction to MR. A suggested use is illustrated in a *YouTube video* illustrating how a Compass needle may, or may not, be excited resonantly when placed in a static field and an orthogonal oscillating magnetic field. The software does not illustrate NMR, which involves angular momentum and therefore differs significantly. Nevertheless, the JavaCompass that illustrates the simplest magnetic resonance phenomenon serves as a convenient starting point for education. When the simple compass dynamics are understood after a few minutes of software use, the role of spin can be added to the explanation to make it pertain to NMR and MRI, differing since the associated angular momentum causes precession rather than vibration. The *software homepage* links to a page where only the Java application itself is displayed *with no additional text*. This is useful when the JavaCompass is introduced in an *exercise* aimed at letting students discover MR for themselves.

Beyond the very basics: The Bloch Simulator

After the basic MR phenomenon is explored, and the role of angular momentum is explained, the real educational challenge starts. The Bloch equations [4] form the basis for almost all MRI techniques, but the enormous potential for advanced applications is not obvious from the equations alone. The student's motivation can be increased and intuition cultivated by supplementing the mathematical descriptions with good visualizations. It is not trivial to visualize basic NMR concepts, but another piece of software, *the Bloch Simulator* [5], comes in handy for illustrating concepts and techniques such as ensemble dynamics, precession, on- and off-resonance excitation, relaxation, dephasing, refocusing, sequences, phase rolls, slice selection, k-space imaging, stimulated echoes and more. The software offers a 3D view of MR vector dynamics controlled interactively via a graphical user interface. A *series of YouTube videos* demonstrates a few example uses. Videos can be used in education but it is much more powerful to use the software interactively for classroom demonstrations [6], which allows for spontaneity and exploration in response to student questions. It is also well suited for exercises where the students operate the software themselves. To facilitate this, the user interface is kept near a bare minimum, and flexibility is to some extent traded off for the simplicity needed in education.

The Bloch Simulator is available in several versions that largely have the same functionality [5]. The latest version implemented in Flash/ActionScript executes in basically any internet browser without installation of software.

Alternatives

A wide range of other software and educational videos are available. In particular, there is a whole range of graphical Bloch equation solvers, which in principle are similar to the Bloch Simulator (e.g. *SpinDemo*, *JEMRIS*, *SIMRI*, *Odin*, and *SpinBench*). Some of these have a quite different focus, however, as they aim at generation of artificial images or simulation of programmed sequences. Whereas interactive use of simple software such as the Bloch Simulator or SpinDemo may be advantageous in most introductory contexts, the more advanced/precise/complicated/flexible software is better in other situations, e.g. for exercises later in courses.

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